CLAIMS

1. A method of determining subsidence in a reservoir, said subsidence resulting from a continual withdrawal of hydrocarbon deposits and other fluids from said reservoir, comprising the steps of:

(a) estimating rock displacement parameters u, v, and w representing rock movement in the x, y, and z directions;

(b) determining $\varepsilon_{x,y,z}$ ('x,y,z elongation strains') and $\gamma_{xy,yz,zx}$ ('shear strains') from the rock displacement parameters u, v, and w;

(c) determining $\sigma_{x,y,z}$ ('elastic normal rock stress in x,y,z directions') and $\tau_{xy,yz,xz}$ ('elastic shear stress') from the $\varepsilon_{x,y,z}$ and $\gamma_{xy,yz,zx}$;

(d) solving a set of rock momentum balance differential equations from the $\sigma_{x,y,z}$ and the $\tau_{xy,yz,xz}$ and determining if any residuals exist, the rock displacement parameters u, v, and w representing accurate rock displacement parameters for said reservoir when the residuals are substantially equal to zero; and

(e) determining said subsidence in said reservoir from said accurate rock displacement parameters determined from step (d), by solving a final set of failure criterion equations, which comprise the residuals and any derivatives, to determine a set of rock plastic displacements, said rock plastic displacements forming a part of said rock displacement parameters u, v, and w.

2. The method of claim 1, wherein the determining step (b) comprises the step of:

determining said $\varepsilon_{x,y,z}$ (the 'x,y,z elongation strains') and said $\gamma_{xy,yz,zx}$ (the 'shear strains') from said rock displacement parameters u, v, and w by using the following equations:

$$\varepsilon_x = \frac{\partial u}{\partial x}$$
$$\varepsilon_y = \frac{\partial v}{\partial y}$$
$$\varepsilon_z = \frac{\partial w}{\partial z}$$
$$\gamma_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}$$
$$\gamma_{yz} = \frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}$$
$$\gamma_{zx} = \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}$$

3. The method of claim 2, wherein the determining step (c) comprises the step of:

determining said $\sigma_{x,y,z}$ (the 'elastic normal rock stress in x,y,z directions') and said $\tau_{xy,yz,xz}$ (the 'elastic shear stress') from said $\varepsilon_{x,y,z}$ and $\gamma_{xy,yz,zx}$ by using the following equations:

$$\sigma_x = 2G\varepsilon_x + \lambda(\varepsilon_x + \varepsilon_y + \varepsilon_z)$$
$$\sigma_y = 2G\varepsilon_y + \lambda(\varepsilon_x + \varepsilon_y + \varepsilon_z)$$
$$\sigma_z = 2G\varepsilon_z + \lambda(\varepsilon_x + \varepsilon_y + \varepsilon_z)$$
$$\tau_{xy} = G\gamma_{xy}$$
$$\tau_{yz} = G\gamma_{yz}$$
$$\tau_{zx} = G\gamma_{zx}$$

4. The method of claim 3, wherein the solving step (d) comprises the steps of:

solving said set of rock momentum balance differential equations from said $\sigma_{x,y,z}$ and said $\tau_{xy,yz,xz}$,

wherein said rock momentum balance differential equations have a left-hand side on a left side of an equal sign and a right-hand side on a right side of said equal sign, said rock momentum balance differential equations including,

$$\frac{\partial \sigma_x}{\partial x}+\frac{\partial \tau_{yx}}{\partial y}+\frac{\partial \tau_{zx}}{\partial z}+F_x+P_x=0$$
$$\frac{\partial \sigma_y}{\partial y}+\frac{\partial \tau_{xy}}{\partial x}+\frac{\partial \tau_{zy}}{\partial z}+F_y+P_y=0$$
$$\frac{\partial \sigma_z}{\partial z}+\frac{\partial \tau_{xz}}{\partial x}+\frac{\partial \tau_{yz}}{\partial y}+F_z+P_z=0$$

said rock displacement parameters u, v, and w estimated in step (a) representing said accurate rock displacement parameters for said reservoir when a left-hand side of said rock momentum balance differential equations substantially equal a right hand side of said rock momentum balance differential equations,

5. The method of claim 4, wherein the solving step (e) comprises the steps of using the said $\sigma_{x,y,z}$ and said $\tau_{xy,yz,xz}$ to determine whether a failure criterion has been exceeded in one of a set of staggered grids.

6. The method of claim 5, wherein, when said failure criterion has been exceeded in said one of said set of staggered grids, the solving step (e) further comprises the step of:

setting up a final set of equations, each equation being a failure criterion approximately equal to zero, and

determining a set of parameters up, vp, wp which are plastic displacements resulting from a failure of the rock, said plastic displacements forming a part of said subsidence and being determined from said accurate rock displacement parameters for said reservoir.

7. A program storage device readable by a machine, tangibly embodying a program of instructions executable by the machine to perform method steps for determining subsidence in a reservoir, said subsidence resulting from a continual withdrawal of hydrocarbon deposits and other fluids from said reservoir, said method steps comprising:

(a) estimating rock displacement parameters u, v, and w representing rock movement in the x, y, and z directions;

(b) determining $\varepsilon_{x,y,z}$ ('x,y,z elongation strains') and $\gamma_{xy,yz,zx}$ ('shear strains') from the rock displacement parameters u, v, and w;

(c) determining $\sigma_{x,y,z}$ ('elastic normal rock stress in x,y,z directions') and $\tau_{xy,yz,xz}$ ('elastic shear stress') from the $\varepsilon_{x,y,z}$ and $\gamma_{xy,yz,zx}$;

(d) solving a set of rock momentum balance differential equations from the $\sigma_{x,y,z}$ and the $\tau_{xy,yz,xz}$ and determining if any residuals exist, the rock displacement parameters u,

v, and w representing accurate rock displacement parameters for said reservoir when the residuals are substantially equal to zero; and

(e) determining said subsidence in said reservoir from said accurate rock displacement parameters determined from step (d), by solving a final set of failure criterion equations, which comprise the residuals and any derivatives, to determine a set of rock plastic displacements, said rock plastic displacements forming a part of said rock displacement parameters u, v, and w.

8. The program storage device of claim 7, wherein the determining step (b) comprises the step of:

determining said $\varepsilon_{x,y,z}$ (the 'x,y,z elongation strains') and said $\gamma_{xy,yz,zx}$ (the 'shear strains') from said rock displacement parameters u, v, and w by using the following equations:

$$\varepsilon_x = \frac{\partial u}{\partial x}$$
$$\varepsilon_y = \frac{\partial v}{\partial y}$$
$$\varepsilon_z = \frac{\partial w}{\partial z}$$
$$\gamma_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}$$
$$\gamma_{yz} = \frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}$$
$$\gamma_{zx} = \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}$$

9. The program storage device of claim 8, wherein the determining step (c) comprises the step of:

determining said $\sigma_{x,y,z}$ (the 'elastic normal rock stress in x,y,z directions') and said $\tau_{xy,yz,xz}$ (the 'elastic shear stress') from said $\varepsilon_{x,y,z}$ and $\gamma_{xy,yz,zx}$ by using the following equations:

$$\sigma_x = 2G\varepsilon_x + \lambda(\varepsilon_x + \varepsilon_y + \varepsilon_z)$$
$$\sigma_y = 2G\varepsilon_y + \lambda(\varepsilon_x + \varepsilon_y + \varepsilon_z)$$
$$\sigma_z = 2G\varepsilon_z + \lambda(\varepsilon_x + \varepsilon_y + \varepsilon_z)$$
$$\tau_{xy} = G\gamma_{xy}$$
$$\tau_{yz} = G\gamma_{yz}$$
$$\tau_{zx} = G\gamma_{zx}$$

10. The program storage device of claim 9, wherein the solving step (d) comprises the steps of:

solving said set of rock momentum balance differential equations from said $\sigma_{x,y,z}$ and said $\tau_{xy,yz,xz}$,

wherein said rock momentum balance differential equations have a left-hand side on a left side of an equal sign and a right-hand side on a right side of said equal sign, said rock momentum balance differential equations including,

$$\frac{\partial\sigma_x}{\partial x} + \frac{\partial\tau_{yx}}{\partial y} + \frac{\partial\tau_{zx}}{\partial z} + F_x + P_x = 0$$
$$\frac{\partial\sigma_y}{\partial y} + \frac{\partial\tau_{xy}}{\partial x} + \frac{\partial\tau_{zy}}{\partial z} + F_y + P_y = 0$$
$$\frac{\partial\sigma_z}{\partial z} + \frac{\partial\tau_{xz}}{\partial x} + \frac{\partial\tau_{yz}}{\partial y} + F_z + P_z = 0$$

said rock displacement parameters u, v, and w estimated in step (a) representing said accurate rock displacement parameters for said reservoir when a left-hand side of said rock momentum balance differential equations substantially equal a right hand side of said rock momentum balance differential equations,

11. The program storage device of claim 10, wherein the solving step (e) comprises the steps of using the said $\sigma_{x,y,z}$ and said $\tau_{xy,yz,xz}$ to determine whether a failure criterion has been exceeded in one of a set of staggered grids.

12. The program storage device of claim 11, wherein, when said failure criterion has been exceeded in said one of said set of staggered grids, the solving step (e) further comprises the step of:

setting up a final set of equations, each equation being a failure criterion approximately equal to zero, and

determining a set of parameters up, vp, wp which are plastic displacements resulting from a failure of the rock, said plastic displacements forming a part of said subsidence and being determined from said accurate rock displacement parameters for said reservoir.